Laser and application :

* **Light** : It is a kind of energy released by an atom. Light is made up of very small particles called photons having energy hν.

* **LASER** – Light Amplification by Stimulated Emission of Radiation. It is a device that amplifies or increase the intensity of light and produces highly directional light.

* **MASER** – Microwave Amplification by Stimulated Emission of Radiation.
  - 1954 using Einstein's idea, C.H Townes and his co-worker invented it.
  - 1960, Theodore Harold Maiman built the first laser device

* **Characteristics of laser** :
Laser light has four unique characteristic that differentiate it from ordinary light. These are
  - Coherance
  - Directionality
  - Monochromatic
  - High intensity.

→ **Coherance** : A fixed relationship b/w the phase of waves in a beam of radiation of a single frequency.

→ **Directionality** : In Conventional light sources (lamp, torchlight), photons will travel in random direction. Therefore, these light source emit light in all directions.
On the other hand, in laser all photons will travel in same direction. Therefore, laser emits light only in one direction. This is called directionally of laser light. The width of a laser beam is extremely narrow. Hence, a laser beam can travel to long distance without spreading.

→ **Monochromatic** : Monochromatic light means a light containing a single colour of Wavelength. In laser, all the emitted photons have the same energy, frequency, or wavelength. Hence, the light waves of laser have single wavelength or colour.

→ **High Intensity** : The intensity of light is the energy per unit time flowing through a unit normal area.

• In laser, the light spreads in small region of space and in a small wavelength range. Hence, laser light has greater intensity when compared to the ordinary light.

→ Absorption ÷ The process of absorbing energy from photons is called absorption of radiation.

$P_{12} = B_{12} u(\nu)$ where B_{12} is proportionality constant and is known as Einstein's coefficient of radiation.

→ Spontaneous Emission ÷ The process by which excited electron emit photons while falling to the ground level or lower energy level is called spontaneous emission.

$\boxed{P_{21} = A_{21}}$ where A_{21} is known as Einstein's coefficient of spontaneous emission of radiation'. In this case the probability of spontaneous emission is independent of it.

→ Stimulated (Induced) emission: The process by which electrons in the excited state are stimulated to emit photons while falling to the ground State or lower energy state is called stimulated emission.

$\boxed{P_{21} = B_{21} u(\nu)}$ where B_{21} is the 'Einstein's Coefficient of stimulated emission of radiation'

• The total probability for an atom in state 2 to drop to the lower state 1 is therefore $\boxed{P_{21} = A_{21} + B_{21} u(\nu)}$

* Relation b/w Einstein's co-effient ÷ $\boxed{\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3}}$

This equation show that the ratio of Einstein's coefficient of spontaneous emission to the Einstein's coefficient of absorption of radiation is proportional to cube of the frequency (ν^3). This means that the probability of spontaneous emission increases rapidly with the energy difference b/w two states.

* Population Inversion :-

- Population inversion is the process of achieving greater population of higher energy state as compared to the lower energy state. Population inversion technique is mainly used for light amplification The population inversion is required for laser operation.

Drawback :- In a 3-level laser, at least half the population of electrons must be excited to the higher energy state to achieve population inversion. Therefore, the laser medium must be very strong pumped This makes 3-level laser inefficient to produce photons or light.

* Components of laser :- There are 3 components :-

i) Pump source
ii) Active medium
iii) Optical Resonator.

- i) Pump source :- The pump source or energy source is the part of a laser system that provides energy to the laser medium. To get laser emission first we need to produce population inversion.
Example :- electric discharges, chemical reaction, flash lamps.

ii) Active medium :- The active medium is a medium in which laser action is made to take place. The laser medium will determine the characteristics of the laser light emitted. (gain medium or laser medium).
Example :- i) Ruby laser :- It is an example solid-state laser. In this, a ruby crystal is used as an active medium. In this laser, xenon discharge tube which provides a flash light acts as pump source.

ii) Helium :- Neon laser is an example for gaseous laser. In this neon is used as an active medium. In this laser, radio frequency (RF) generator acts as pump source.

iii) optical Resonator :- A part of a laser consisting of two mirrors, one highly reflective and one partly reflective, placed on either side of a laser pump.

$$l = \frac{n\lambda}{2}$$

l = length of cavity
λ = wavelength of laser.

* Method of Achieving Population Inversion :-

1) optical pumping.
2) Electric discharge or excitation by electrons.
3) Inelastic atom-atom collisions.
4) Direct conversion.
5) chemical reactions.

* Ruby laser :- It emits deep red light of wavelength 694.3nm

Construction :- It has 3 component :- laser medium, pump source, optical resonator.

i) laser medium :- In ruby laser, a crystal of ruby ($Al_2O_3 : Cr^{3+}$) in the form of cylinder acts as a laser medium. It is made up of Al_2O_3 dopped with small amount of chromium ions. The length of rod is about 2-30cm and diameter is 0.5-2cm.

ii) Energy source :- In this xenon flashtube is used as the energy source. It is used to excite the electrons to change the level.

iii) optical Resonator: The ends of the cylindrical ruby rod are flat and parallel. The cylindrical ruby rod is placed b/w two mirror. one mirror is fully silvered and another is partially silvered which allow the small portion of light through it to produce output laser light.

* He-Ne laser :- This is 4-level as laser which produces continuous wave.

Construction: ① Pump Source ② Grain medium ③ Resonating cavity.

i) Mixture of gases He-Ne is 10:1
2) Discharge tube 50cm length, 1cm diameter.
3) Inside pressure is low at 1 torr.
4) spacing of the mirror is equal to an integral number of half-wavelength.

632.8nm → nano meter

Working :- • when the power is switched on
• He atom excited to 20.61eV. then give energy to unexcited Ne atom.
• Ne atom transit to 20.66eV population inversion achived.
• Ne-atom transit from 20.66eV to 18.70 eV.
• Stimulation process occurs.
• laser having 632.8 nm emits.

* Advantages of He-Ne laser

i) High stability.

ii) low cost

iii) operates without damage at higher temperature.

Application :-

• Helium neon laserser used in industries, scientific instruments, labs.

* ND:YAG laser :- (neodymium Yttrium Aluminium Garnet). ($Y_3Al_5O_{12}$).

• It was developed by J.E. Geusic, H.M, Marcos and L.G Van Vitert in 1964.

• Nd:YAG is a solid state laser.

• It is 4-level laser.

Construction :- i) The rod $Y_3Al_5O_{12}$ is dopped with 1% neodymium ions and Y^{3+} ions replace by Nd^{3+} ions.

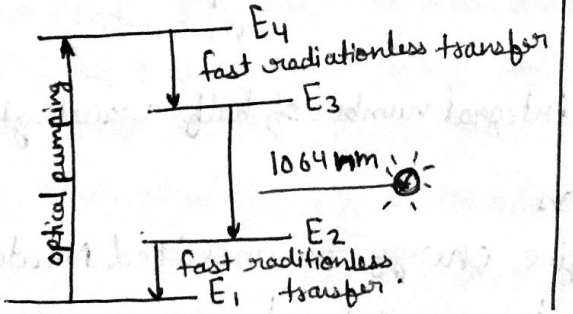
ii) The maximum length of the rode is 10cm and diameter is 6-9cm.

iii) Active medium : Nd^{3+} ions acts as an active medium or active centers. YAG is just host.

iv) Pumping source is xenon flash lamp or krypton flash lamp which excited Nd^{3+} ions to upper level.

v) Optical Resonator :- The ends of YAG rod are polished and silvered so as act as optical resonator.

* Working Principle :-



Advantages :-

→ Continous wave is emitted

→ low power consumption.

→ It offers high gain

→ It has good thermal properties.

→ The efficiency of Nd-YAG laser is very high (2%) as compared to the ruby laser (0.1%).

Applications :- i) Medical :- In cancers, to correct posterior capsular opacification.

ii) Used in removing skin cancers.

iii) cutting and welding.

iv) Military.

* Semiconductor laser :-

→ In 1962, the 1st semiconductor laser at low temperature was developed by R.N. Hall and coworkers in USA.
→ GaAs is used to make semiconductor laser.
→ This laser is produces light in the infrared region (IR).
→ Later semiconductor laser was developed in the visible region at room temperature.

* Advantages :- i) Simple construction
ii) Lightweight and portable
iii) Low cost
iv) Small size (0.1mm long)
v) Longer operating life.
vi) Highly reliable compared to other types of lasers.
vii) long operating life.
viii) Highly efficient (40%)
ix) Low power consumption.
x) Mirrors are not required.

* Disadvantages
- Not suitable for the applications where high powers are required
- Semiconductor lasers are highly dependent on temperature.

* Application :-
- laser diodes are used in laser pointers.
- used in fiber optic communication
- laser diodes are used in barcode reader.
- laser diodes are used in laser print.
- finding longe range.

* Application of laser :-
→ lasers in medicine
→ lasers in communications
→ lasers in industries
→ lasers in science and technology.
→ lasers in military.

Ques → Find the intensity of LASER beam of 100 mW power and having a diameter of 1.3mm?

Solution → diameter of beam = $1.3\,mm = 1.3 \times 10^{-3}\,m$

Area of beam = $\pi r^2 = \pi \left(\frac{D}{2}\right)^2 = 3.14 \times 0.4225 \times 10^{-6}$
$= 1.327 \times 10^{-6}\,m^2$

Power = $100\,mW$
$= 100 \times 10^{-3}\,W = 10^{-1}\,W$

Intensity = $\frac{P}{A} = \frac{10^{-1}}{1.327 \times 10^{-6}\,m^2} = 7.53 \times 10^{4}\,W m^{-2}$

Hence, the laser beam intensity is $7.536 \times 10^{4}\,W m^{-2}$

Ques ÷ A He-Ne laser giving light at 7000Å has a coherence length of 20km. Determine its coherence time?

Solution ÷ $l_L = 20\,km = 2 \times 10^4\,m$

Wavelength of light $\lambda = 6330 \times 10^{-10}\,m$

Coherence time, $T_L = \frac{l_L}{C} = \frac{2 \times 10^4}{3 \times 10^8} \Rightarrow 6.7 \times 10^{-5}\,sec.$

Ques ÷ Given a laser light beam of power 20mW is focused on a target by a lens of focal length 0.05 m. If the Aperture of the laser be 1mm and the wavelength of its light 7000 Å. Calculate the angular spread of the laser, the area of the target hit by it and the intensity of impact on the target.

Sol ÷ $P = 20\,mW = 20 \times 10^{-3}\,W$

focal length $f = 0.05\,m$, $d = 1mm = 1 \times 10^{-3}\,m$, $\lambda = 7000Å = 7000 \times 10^{-10}$

theta $= 7 \times 10^{-4}$ radians.

Linear spread of laser = f x theta

$= 0.05 \times 7 \times 10^{-4} \Rightarrow 0.35 \times 10^{-4}\,m$

area targeted $= s^2$

$\Rightarrow (0.35 \times 10^{-4})^2$

$\Rightarrow 0.1225 \times 10^{-8}$

$\Rightarrow 1.225 \times 10^{-9}$ sq.m.

So, intensity $= \frac{20 \times 10^{-3}}{1.225 \times 10^{-9}} = 16.326 \times 10^6\,W/m^2$

Ques ÷ A certain Ruby laser emits 1.00 J pulses of light whose wavelength is 6940Å. what is the minimum number of Cr^{3+} ions in the ruby?

Sol ÷ $\text{Power} = \frac{nhc}{\lambda}$

$1.00\,J = \frac{n \times 6.62 \times 10^{-34} \times 3 \times 10^8}{6940 \times 10^{-10}} \Rightarrow 3.39 \times 10^{18}$ ions.

Ques ÷ Find the ratio of population of the two states in a He-Ne laser that produces light of wavelength 6328 Å at 27°C.

Sol ÷ $\frac{N_2}{N_1} = e^{-(E_2 - E_1)/KT}$.

$E_2 - E_1 = \frac{12400}{\lambda}\,eV = \frac{12400}{6.328}\,eV = 1.96\,eV.$

$\frac{N_2}{N_1} = e^{(-1.9eV)/(8.61 \times 10^{-5}\,eV \times 300K)}$

$= e^{-75.88} = \boxed{1.1 \times 10^{-33}\ \text{Ans.}}$